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September 3, 2013

Via Electronic Filing

Marlene H. Dortch
Secretary
Federal Communications Commission
445 12th Street SW
Washington, DC 20554

Re: Notice of Ex Parte Communication: *Amendment of the Commission's Rules with Regard to Commercial Operations in the 3550-3650 MHz Band*, GN Docket No. 12-354

Dear Ms. Dortch:

On August 29, 2013, Austin Schlick, Dr. Preston Marshall, and I met with the following members of the Wireless Telecommunications Bureau, Office of Engineering and Technology, and International Bureau to discuss the points set forth in the attached letter and supporting declaration.

Wireless Telecommunications Bureau
John Leibovitz
Brian Regan
Paul Powell
Kamran Etemad

Office of Engineering and Technology
Renee Gregory
Mark Settle
Robert Pavlak
Bryant Wellman
Garth Hahn
Navid Golshahi

International Bureau
Robert Nelson
Paul Blais
Chip Fleming

Pursuant to the Commission's rules, this notice is being filed in the above-referenced docket for inclusion in the public record. Please contact me should you have any questions.

Respectfully submitted,

Aparna Sridhar

Aparna Sridhar
Telecom Policy Counsel
Google Inc.

Enclosures
cc: All Attendees *(via electronic mail)*

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September 3, 2013

Via Electronic Filing

Mr. Julius Knapp, Chief, Office of Engineering and Technology
Ms. Ruth Milkman, Chief, Wireless Telecommunications Bureau
Federal Communications Commission
445 12th Street, SW
Washington, DC 20554

Re: *Amendment of the Commission's Rules with Regard to Commercial Operations in the 3550-3650 MHz Band*, GN Docket No. 12-354

Dear Mr. Knapp and Ms. Milkman:

In February, the Commission issued a Notice of Proposed Rulemaking proposing to establish a Citizens Broadband Service ("CBS") in the 3.55 GHz band, and to allow commercial or noncommercial entities to use the spectrum while protecting government incumbents in the band.[1] Google strongly supports opening up this band for small cell wireless broadband use and employing spectrum access system ("SAS") databases to protect incumbent users from harmful interference.[2]

Some users of the neighboring C-band spectrum at 3.7 to 4.2 GHz have raised concerns about potential harmful interference to their operations.[3] Those concerns can be resolved through straightforward interference mitigation techniques that will allow CBS small cell users and C-band users to coexist in their respective bands.

1. Readily available filters can reduce interference C-band users may experience from listening for transmissions below 3.7 GHz.

Content providers and broadcasters maintain a network of satellites and associated earth stations to deliver television and radio programming to locations across the country. Satellites use C-band frequencies allocated by the Commission to transmit content to earth stations. The earth stations receive the satellite transmission and relay content to end users. Although the band allocated for domestic C-band transmissions in the United States is narrower than the band used in other countries, many U.S. earth station operators

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[1] *See generally Amendment of the Commission's Rules with Regard to Commercial Operations in the 3550-3650 MHz Band*, Notice of Proposed Rulemaking and Order, GN Dkt. No. 12-354 (rel. Dec. 12, 2012) ("NPRM"). The term "3.55 GHz band" here refers to the spectrum between 3.55 and 3.7 GHz.

[2] *See* Comments of Google Inc., GN Dkt. No. 12-354 (filed Feb. 20, 2013).

[3] *See* Alion Consulting Report, Reply Comments from CBS Corporation, National Association of Broadcasters, News Corporation, Time Warner Inc., Viacom Inc., and the Walt Disney Company, Attach. at 1, GN Dkt. No. 12-354 (filed Apr. 5, 2013) ("Alion"); Comsearch Technical Paper, Letter from CBS Corporation, National Association of Broadcasters, News Corporation, Time Warner Inc., Viacom Inc., and the Walt Disney Company, to Marlene H. Dortch, Secretary, Federal Communications Commission, Attach. at 3, GN Dkt. No. 12-354 (filed on May 8, 2013) ("Comsearch"); Engineering Statement of Skjei Telecom, Reply Comments of the National Association of Broadcasters, Attach. at 1, GN Dkt. No. 12-354 (filed on Feb. 20, 2013) ("NAB"). "C band" refers to the spectrum between 3.7 GHz and 4.2 GHz, which earth stations use to receive satellite television and radio transmissions.

chose to install C-band signal receiving devices that are designed for international (rather than U.S.) use, and therefore "listen" outside the U.S. C-band frequencies.[4] These C-band receiving devices are designed to pick up transmissions over frequencies as low as 3.4 GHz, *fully 300 MHz below the lower edge of the 3.7-4.2 GHz C-band spectrum allocated by the Commission for this country*.

Content providers and broadcasters assert that small cell operations in the 3.55 GHz band would cause interference to C-band earth stations that listen outside their authorized spectrum, in the adjacent 3.55 GHz band.[5] They assume that C-band users should not be expected to conform their receivers in the United States to the FCC's C-band allocation and, to the extent they discuss filtering at any length, they largely dismiss it as a means of mitigating interference.[6] At the extreme, the Satellite Industry Association relies on a study performed by the ITU to claim a need for huge protection zones to safeguard C-band earth stations.[7] Because the ITU study assumes that C-band satellite operations have spectrum allocations to operate as low as 3.4 GHz, SIA's analysis grossly overstates potential interference to protected U.S. C-band operations.[8]

The Commission has recognized that at a time of rapidly increasing demand for spectrum, it is reasonable to require users to deploy filters to protect their equipment against the authorized, in-band operations of adjacent operators.[9] Were it otherwise, users could effectively claim rights to more spectrum than the Commission granted them.

Because earth station operators can easily install filters to protect themselves from interference caused by listening outside their authorized band, the Commission should not delay opening the 3.55 GHz band based on C-band concerns. As noted, these receivers listen as much as *300 MHz* outside of their assigned 3.7-4.2 GHz range. The nation simply cannot afford to allow C-band operators to render that huge amount of spectrum unusable when there is a technically feasible alternative.

Here, the alternative is not just technically feasible, but also routinely deployed. To ensure high-quality video reception, many C-band television operators already use filtering to protect against potential interference caused by high-powered military radars that are incumbent users in the 3.5-3.7 GHz band.[10] Vendors typically market these filters as "radar elimination filters," but they are not specific to radar interference, and can be used to filter out small cell interference as well.[11] Such filters are widely available for

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[4] *Notice* at ¶ 29.

[5] *See, e.g.*, *Alion* at 1; *Comsearch* at 3; *NAB* at 1.

[6] Notably, Comsearch acknowledges that filtering "should be effective to mitigate interference caused by transmitters in the 3.55-3.65 GHz," raising concerns only about the 3.65-3.7 GHz band. *Comsearch* at 7.

[7] *See* Letter from Patricia Cooper, President, Satellite Industry Association, to Marlene H. Dortch, Secretary, Federal Communications Commission, GN Dkt. No. 12-354 (filed Aug. 20, 2013) (SIA August 20 Letter).

[8] *See id.*, Attach. at 2. A relative handful of earth stations are permitted to operate in the spectrum between 3.6 GHz and 3.65 GHz. There are less than 40 such facilities nationwide, and the Commission has ceased granting new applications during the pendency of this proceeding. *See* NPRM at ¶ 154. Interference to the existing stations can be managed by an SAS database, as described below.

[9] *See Service Rules for Advanced Wireless Services in the 2000-2020 MHz and 2180-2200 MHz Bands,* Report and Order, FCC 12-151, ET Dkt. No. 10-142, at ¶ 138 (rel. Dec. 17, 2012).

[10] *See Declaration of Dr. Preston Marshall, Ph.D.* ("Declaration"), at ¶¶ 8-10.

[11] *Id.*

less than $500; typically, only two filters are required per C-band dish.[12] Furthermore, because C-band bandpass filters are intended for use with industry-standard receiver equipment, most C-band satellite receivers can be retrofitted.[13] Installation of a filter does not impair effective operation of the satellite receiver—it results in only minimal degradation.[14]

Google's own experience confirms this. Google Fiber uses C-band dishes at its national headend in Council Bluffs, Iowa, to support its Internet Protocol television ("IPTV") service.[15] Google Fiber equipped its dishes with bandpass filters at the time of construction, before the Commission adopted the NPRM in this proceeding, as a matter of course. Google adopted this routine and commonplace method to limit interference and assure the best quality video reception for Google Fiber's IPTV users.[16]

To be sure, filtering may be more difficult where C-band operators have installed multi-beam antennas on their earth stations. Such antennas allow operators to receive more programming using a single dish that "listens" to more than one satellite, rather than focusing one dish on one satellite in the industry-standard manner). Commercial multibeam filters are available today, however.[17] In any event, multibeam operators made a business choice to configure their systems in a risky way that is more exposed to signals outside their allocated C-band spectrum, and more difficult to protect with filters. The operators' shortcut is not a sufficient reason to preclude small cell operations in the adjacent 3.55 GHz band. To the extent that multi-beam antennas continue to listen out of their band and cannot be protected with filters, C-band operators can replace multi-beam antennas with single-beam dishes that perform the same function with less susceptibility to out-of-band interference.

In sum, filtering adjacent band interference is a tested and effective solution for C-band satellite dishes. Indeed, the protection provided by commercially available products mitigates interference concerns associated with C-band earth stations using frequency below their allocated band, to the extent that this issue requires no additional remedial action besides what is needed to protect C-band earth stations against the minimal out-of-band emissions from CBS devices into the 3.7-4.2 GHZ range.[18] Accordingly, we now turn to that issue.

2. **Emissions from CBS operations into the C-band will cause minimal interference, and that interference can be mitigated.**

C-band users have offered studies from Alion and Comsearch that purport to demonstrate that out-of-band emissions from small cells in the 3.55 GHz band, into the C band, will cause harmful interference.

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[12] C-band filters are sold by a number of retailers, including Microwave Filter Company, Inc., http://www.mfcsales.com/radarelimination.aspx; Sotca, Inc., http://www.sotca.com/products/filters.aspx; Eagle Comtronics, Inc., http://www.eaglecomtronics.com/index.html?MainCategory=MainSatellite; Nickless Schirmer & Co., http://www.nsccom.com/7893d.aspx; Vincor, Ltd., http://catalog.vincor.com/ProductDetails.asp?ProductCode=MFC-13961.

[13] *Declaration* at ¶ 8.

[14] *Declaration* at ¶ 9.

[15] *Id.*

[16] *Id.*

[17] *See, e.g.*, C-Band Interference Filters, http://www.dawnsat.com/auto_links/pdf/C-BANDPASS-6Light.pdf (last visited Aug. 30, 2013). *See Declaration* at ¶ 11.

[18] *Declaration* at ¶ 10.

In reality, CBS out-of-band emissions are likely to affect C-band receiver operations only if small cell devices are in close physical and spectral proximity to the C-band receiver. In these situations, an SAS database as proposed by the Commission can protect C-band operations.

The level of out-of-band emissions interference to earth station operations from a small cell device depends on physical separation, spectral separation, the elevation angle of the earth station, and the CBS device's position relative to the line between the satellite beam and the earth station's directional antenna. Increased physical and spectral separation decrease interference. That is, if a device is physically farther away from a satellite earth station, then it is less likely to cause harmful interference to satellite operations. Similarly, small cell devices that operate on spectrum not immediately adjacent to the lower bound of the C band (at 3.7 GHz) are less likely to cause interference than devices in immediately adjacent spectrum.[19]

The elevation angle defines the position of the satellite relative to the receiver earth station. The elevation angle is set to maximize the amount of signal energy captured from the satellite, and it affects the physical distance at which the earth station receiver becomes susceptible to interference. When a satellite is directly above an earth station, the elevation angle of the dish is 90°; when the satellite is less elevated above the horizon, the dish's elevation angle is smaller. A small elevation angle—which typically occurs when an earth station is receiving transmissions from a satellite that is located far to the east or the west of the earth station—makes the earth station receiver more sensitive to interference from terrestrial devices' out of band emissions.[20]

Similarly, the device's position relative to the angle of the satellite beam can affect susceptibility for interference: Signals from devices directly in front of low elevation angle dishes are not rejected as strongly by the antenna as those that are far from the main beam.[21] This is significant because, in most cases, a nearby small cell device will not be directly in front of a dish.

Comsearch's analysis suggests standoff distances for various devices in relation to a C-band earth station.[22] Standoff is the distance that must be maintained from a device to avoid interference to the earth station from out-of-band emissions. Comsearch concludes that the standoff distance between typical small cell devices and typical earth stations would be between 700 meters (less than a half mile) and 5.1 kilometers.[23] Comsearch uses these standoff distances as radii to compute fixed, circular exclusion zones.[24]

As an initial matter, Comsearch's circular exclusion zones ignore device position. A more thorough calculation takes into account, first, the angle and direction of the receiver antenna, resulting in exclusion zones that range from nearly round but much smaller than Comsearch suggests (for typical earth station elevation angles) to longer but very narrow (for depressed elevation angles).[25] In each case, Comsearch's exclusion zones are unnecessarily restrictive, preventing device operation across a greater area than what is required to protect the earth station. Furthermore, as noted above, additional factors including spectral

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[19] *Declaration* at ¶ 12-14.

[20] *Declaration* at ¶ 18-19.

[21] *Declaration* at ¶ 20.

[22] *Comsearch* at 10.

[23] *Comsearch* at 12.

[24] *Comsearch* at 3.

[25] *Declaration* at ¶ 27 & Figure 2.

separation affect the earth station's susceptibility to interference. These factors, too, can allow protection zones that are much smaller than the ones Comsearch suggests.

Instead of restricting the use of devices to operation outside of a static protection contour based on a worst-case set of assumptions, an SAS database can protect C-Band operations while ensuring maximum CBS utility by assessing device location and frequency characteristics, earth station elevation angle, and device aggregation when determining separation needs. In all cases, setting a static protection contour with a radius of hundreds or thousands of meters, as Comsearch suggests, would over-protect earth stations.

A. Effect of spectral separation

Spectral separation mitigates significantly the potential for out-of-band interference. Using the parameters submitted by Alion Consulting for a device occupying a 10 MHz channel, a spectral separation of 14.75 MHz from the C band is sufficient to reduce the physical separation distance needed to attain an interference-to-noise ratio of less than 0.1 by a factor of more than 100 (e.g., from 2 kilometers to less than 20 meters) in free space.[26] The interference-to-noise ratio is an indicator of system performance, and a low ratio typically corresponds with strong signal reception.[27] A ratio as low as 0.1 or less suggests that any interference is likely to pass through the C-band receiver undetected, and such a ratio is consistent with a commonly used, recommended interference objective for earth station receivers.[28] Thus, a relatively small spectral separation should be able to protect C-band operations. This analysis, it should be noted, is very conservative because it does not take into account additional propagation loss, significant polarization loss, and absorption by building materials, foliage and other terrestrial path blockages, all of which further reduce the energy carried out of the band.[29]

B. Effect of the elevation angle

The C-band receivers that are most likely to require protection from out-of-band emissions of terrestrial CBS devices are those with a very depressed elevation angle, close to the horizon. As noted above, elevation angle varies as an earth station looks at satellites to the east or west of the station. So, for example, to receive transmissions from the AMC-8 C-band satellite positioned above Hawaii, the optimal elevation angle for a receiver in Los Angeles, San Francisco, or San Diego is about 44° above the horizon.[30] When the elevation angle is that elevated, small cell devices can operate in close proximity to an earth station without risk of interference.[31] Receivers in the vicinity of Atlanta, Miami, and Charlotte use a elevation angle of about 20° to look at the same satellite over Hawaii, still permitting operations reasonably close to the earth station.[32] Lower elevation angles warranting additional protection from interference typically occur only in the extreme northeastern United States, where earth stations must listen for transmissions coming from the south and west. Even there, low-elevation earth stations are unlikely to be operating in urban areas, because the earth

[26] *Declaration* at ¶ 15.

[27] *See Declaration* at ¶ 12.

[28] Int'l Telecomm. Union [ITU], *Determination of the Interference Potential Between Earth Station of the Fixed-Satellite Service and Stations in the Fixed Service,* Recommendation ITU-R SF.1006 (1993).

[29] *Declaration* at ¶ 16.

[30] *Declaration* at ¶ 19 and Figure 1.

[31] *Declaration* at ¶ 19.

[32] *Id.*

station needs a clear line of sight to the satellite; modestly high trees or buildings as low as two stories would impede adequate visibility.[33]

Considering these factors and using a series of extremely conservative assumptions, an average protection area for each earth station would be approximately 0.285 square kilometers.[34] Multiplying 0.285 square kilometers by the roughly 5,000 C-band earth stations yields a total area of at very most 1,425 square kilometers in which small cell devices might not be able to operate. The actual total area based on conservative assumptions would be significantly lower; many earth stations are located in close proximity to other earth stations, so their real-world protection zones will overlap.[35] A protection area of 1,425 square kilometers represents less than 0.015% of the United States' land mass, with the actual C-band protection area being substantially less.[36] The protected areas, moreover, are likely to be suburban and rural, and therefore comparatively sparsely populated.[37] Finally, the areas where C-band protection is given will sometimes overlap with the areas where CBS operations already are restricted to protect the federal radar systems that are incumbents in 3.55 GHz band spectrum. In such areas of overlap, C-band protections are operationally inconsequential. For all these reasons, it can safely be assumed that C-band earth stations can be protected through restrictions that affect much less than 0.015% of the U.S. land mass.

In sum, there are relatively few earth stations requiring protection from interference, and protecting them from harmful interference when they operate within the C band will not impede widespread deployment of devices in the 3.55 GHz band.

C. Effect of the device position relative to the angle of the satellite beam

As noted above, small cell devices pose a greater risk of interference to C-band operations when they operate directly below the beam of the earth station. For example, a maximum protection distance of up to 1.67 kilometers might be warranted if a CBS small cell device were to operate directly in line with the beam of a dish with a 5° elevation angle.[38] As discussed, however, the protection distance is much less when the CBS device is operating off that line. Indeed, the protection distance drops to just 250 meters when the device is only ⅛ of a turn (about 45°) off the direct angle of the beam.[39] Thus, the circumstances in which significant protection may be warranted are limited to those in which a CBS device is directly or nearly in the angle of the beam.

D. The role of SAS databases

Physical separation, spectral separation, elevation angle, and device position relative to the satellite beam all affect a C-band receiver susceptibility to out-of-band emissions interference. To ensure appropriate protection from CBS devices' out-of-band emissions, C-band users will be able to register with an SAS geolocation database. The Commission's rules should accord databases the flexibility to take into account all

[33] *Declaration* at ¶ 28 and 30b.

[34] *Declaration* at ¶ 26.

[35] *Declaration* at ¶ 24.

[36] Land mass includes bodies of water that are part of the contiguous United States, but not ocean territory or overseas possessions.

[37] *Declaration* at ¶ 28.

[38] *Declaration* at ¶ Table 2.

[39] *Id.*

relevant parameters to maximize spectral utility, and a sophisticated SAS database can evaluate the likelihood of interference in real time based on the beam direction and elevation angle of a registered C-band earth station and the spectral and physical location of the small cell device. Based on the possibility of interference, an SAS database can dynamically limit the operation of the small cell device to an appropriate separation distance from the earth station.

A sophisticated SAS database will also address the aggregate impact of small cell devices on C-band receivers because it will be aware of all of the CBS devices in operation in a given locality and the local propagation conditions. As a result, an SAS database can not only protect C-band operations from individual CBS devices, but also ensure that aggregate out-of-band emissions from CBS devices do not exceed a registered earth station's interference threshold. Allowing databases to incorporate these inputs doesn't imply that the Commission should require all databases to have the same level of sophistication—only that databases that take additional factors into account will define protected areas more precisely, allow small cell operations in larger geographic areas, and thus be favored by small cell operators.

The SAS database approach will similarly encourage the development and deployment of better-performing CBS devices. The Comsearch analysis discussed above reveals significantly different standoff distances for small cell devices with different performance.[40] And the SIA analysis results in extreme protection levels in part because it assumes theoretical worst-case out-of-band emissions performance, rather than the performance of actual devices in the field.[41] Because an SAS database would resolve conflicts between CBS devices and protected incumbents based in part on the CBS device's performance level as determined during the Commission's device certification process, CBS devices with lesser out-of-band emissions will have greater opportunity to receive spectrum assignments. In some situations, poor out-of-band performance may completely preclude operation of a poorer-performing CBS device at a location where better-performing devices could be allowed. While the Commission should establish some minimum level of out-of-band emissions performance for CBS devices,[42] an SAS-managed approach will create in the 3.55 GHz band the same economic incentives that have caused the WiMAX and 3GPP communities themselves to adopt performance levels in excess of regulatory requirements.[43]

3. If necessary, a combination with coordination techniques and SAS-based spectral and physical separation can accommodate protection of grandfathered earth stations between 3.6 and 3.65 GHz

There are a small number of earth stations (approximately 37) that operate in the band between 3.6 and 3.65 GHz.[44] These earth stations generally are used for point-to-point communications services that can be provided using alternative technologies such as fiber-optic delivery. Nevertheless, assuming that these few earth stations remain in service, an SAS database can protect them from disruption of their operations through a combination of coordination, spectral separation, and protection zones.

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40 *Comsearch* at 10.

41 *See* SIA August 20 Letter, Attach. at 5. Both Google and Alion used devices that comply with the WiMax specifications as exemplars. The WiMax emission mask is much more efficient than the theoretical masks discussed in the SIA letter. *In close proximity to an earth station, even small improvements in the mask (for example, a 6 dB reduction) can halve the exclusion distance and reduce the protection area by approximately 75%.*

42 NPRM at ¶ 138.

43 IEEE Standards Association, *IEEE Standard for Air Interface for Broadband Wireless Access Systems*, IEEE STD 802.16™-2012 (17 Aug. 2012).

44 NPRM at ¶ 23.

The recent SIA analysis grossly overstates potential interference to operations of these earth stations in the 3.6-3.65 GHz band.[45] First, the document relies on an interference protection standard developed by the International Telecommunication Union to address spurious emissions from other bands; the standard was not intended to address the question of what level of emissions would be appropriate for co-channel operations.[46] Second, the analysis combines terrain assumptions appropriate for a flat state like Florida with elevation-angle assumptions likely to occur in a northeastern state like Maine, creating counterfactual worst-of-worst case scenarios. Third, the SIA analysis assumes that small cell devices would have very poor emissions performance, rather than relying on standards like WiMax that approximate the performance of actual devices in the field. Fourth, the SIA analysis assumes that devices would operate at power levels up to 13 decibel-watts, which is many times higher than typically proposed for household use. All of these assumptions combined result in dramatically overstated conclusions regarding the potential for harmful interference to these 37 earth stations.

* * * * *

Google supports the Commission's goal of maximizing efficient use of spectrum to meet the growing demand for wireless capacity. We look forward to working with the Commission and C-band users to resolve their concerns about small cell use of the 3.55 GHz band, consistent with this national goal. Please do not hesitate to contact me if you have questions about this filing or if I can be of further assistance.

Respectfully submitted,

Aparna Sridhar

Aparna Sridhar
Telecom Policy Counsel
Google Inc.

[45] Letter from Patricia Cooper, President, Satellite Industry Association, to Marlene H. Dortch, Secretary, Federal Communications Commission, GN Docket No. 12-354 (filed Aug. 20, 2013) (SIA August 20 Letter), Attach.

[46] *Compare id.*, Attach. at 6 (citing Recommendation ITU-R S.1432) *with* ITU-R Recommendation S.1342 (2006) at 3 ("There are no Recommendations pertaining to the amount of interference that a digital satellite circuit will receive from systems that share frequencies on a non-primary basis.").

Before the
FEDERAL COMMUNICATIONS COMMISSION
Washington, D.C. 20554

In the Matter of Amendment of the Commission's Rules with Regard to Commercial Operations in the 3550-3650 MHz Band	GN Docket No. 12-354

DECLARATION OF DR. PRESTON MARSHALL, Ph.D.

1. My name is Preston Marshall. I am the Principal Systems Architect for Google Access Services. I also served as an invited expert to the President's Council of Advisors on Science and Technology (PCAST) and contributed to PCAST's 2012 report titled "Realizing the Full Potential of Government-Held Spectrum to Spur Economic Growth."[1] Before joining Google, I served as a Professor of Electrical Engineering and the Deputy Director of the Information Sciences Institute at the University of Southern California in Los Angeles, California. I also worked for many years at the Defense Advanced Research Projects Agency. I received a Ph.D. from Trinity College in Dublin. I also received an M.S. in Information Science and a B.S. in Electrical Engineering from Lehigh University.

2. I have worked extensively on matters regarding systems design and architecture, wireless technologies, interference, network design, and spectrum

[1] PCAST, *Report to the President: Realizing the Full Potential of Government-Held Spectrum to Spur Economic Growth* (rel. July 20, 2012).

management in general. I also have specific expertise in designing databases to enable spectrum sharing between various types of users.

3. I have reviewed the FCC's Notice of Proposed Rulemaking ("NPRM") titled *Amendment of the Commission's Rules with Regard to Commercial Operations in the 3550-3650 MHz Band*.[2] I have also reviewed the following items filed in response to the Commission's NPRM: a Consulting Report produced by Alion Consulting titled "Effects of the Proposed Citizens Broadband Service to C-band DOMSAT Earth Stations," a technical paper produced by Comsearch titled "Estimating the Required Separation Distances to Avoid Interference from Citizens Broadband Service Transmitters into C-Band Earth Stations," and an Engineering Statement by Skjei Telecom, Inc.[3] This declaration contains my analysis of certain technical matters related to the protection of C-band earth stations from harmful interference that may be caused by small cell devices operating in the spectrum between 3.55 and 3.7 GHz (the "3.55 GHz band").

4. The technical analyses I reviewed purport to demonstrate that allowing small-cell devices to operate in the 3.55 GHz band—directly below the spectrum at 3.7 GHz—raises significant concerns regarding interference to existing operations in the

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[2] *Amendment of the Commission's Rules with Regard to Commercial Operations in the 3550-3650 MHz Band*, Notice of Proposed Rulemaking and Order, GN Dkt. No. 12-354 (rel. Dec. 12, 2012).

[3] *See* Alion Consulting Report, Reply Comments from CBS Corporation, National Association of Broadcasters, News Corporation, Time Warner Inc., Viacom Inc., and the Walt Disney Company, Attach. at 1, GN Dkt. No. 12-354 (filed Apr. 5, 2013) ("Alion"); Comsearch Technical Paper, Letter from CBS Corporation, National Association of Broadcasters, News Corporation, Time Warner Inc., Viacom Inc., and the Walt Disney Company, to Marlene H. Dortch, Secretary, Federal Communications Commission, Attach. at 3, GN Dkt. No. 12-354 (filed May 8, 2013) ("Comsearch"); Engineering Statement of Skjei Telecom, Reply Comments of the National Association of Broadcasters, Attach. at 1, GN Dkt. No. 12-354 (filed Feb. 20, 2013) ("NAB").

3.7-4.2 GHz band (the C-band).[4] Specifically, the technical analyses identify concerns that adjacent band interference and out-of-band emissions (OOBE) will disrupt earth station operations. Based on my analyses and experience, I believe that small-cell devices can be deployed in the 3.55 GHz band without substantially affecting earth station operations. Any concerns regarding interference can be mitigated by installing filters that already are widely available and by using a spectrum access database to manage out-of-band emissions from small-cell devices.

5. The analysis in this declaration emphasizes the real-time, dynamic capabilities of a deployed spectrum access system (SAS) database. The exclusion zones calculated by the SAS are significantly impacted by the availability of information regarding both the registered C-band operation and the small-cell device. Accordingly, I made the following assumptions regarding the information that would be available to an SAS database:

- C-band user location: Would be received via C-band user registration.
- C-band user interference thresholds: I used established ITU standards and typical commercial receiver performance.
- C-band user filtering (where applicable): I referred to state of the practice commercial filters.

[4] *See* Alion Consulting Report, Reply Comments from CBS Corporation, National Association of Broadcasters, News Corporation, Time Warner Inc., Viacom Inc., and the Walt Disney Company, Attach. at 1, GN Dkt. No. 12-354 (filed Apr. 5, 2013) ("Alion"); Comsearch Technical Paper, Letter from CBS Corporation, National Association of Broadcasters, News Corporation, Time Warner Inc., Viacom Inc., and the Walt Disney Company, to Marlene H. Dortch, Secretary, Federal Communications Commission, Attach. at 3, GN Dkt. No. 12-354 (filed May 8, 2013) ("Comsearch"); Engineering Statement of Skjei Telecom, Reply Comments of the National Association of Broadcasters, Attach. at 1, GN Dkt. No. 12-354 (filed Feb. 20, 2013) ("NAB").

- Small-cell device location: I assumed devices would supply accurate location information. Location information will be required not only to protect C-band users, but also to provide protection for federal incumbents and preclude harmful interference to secondary access users.
- Small-cell device OOBE masks: I used industry criteria for certification. This example analysis used the WiMAX OOBE mask, but in actual operation an SAS database could use the vendor's compliance or FCC evaluation data to more accurately determine interference potential.

6. It is not necessary that all of this information be available to an SAS database. With limited information, an SAS database will have to be more conservative in its assumptions, and therefore might provide fewer spectrum sharing opportunities.[5]

Using Filters to Mitigate Interference Caused by C-band Operations Listening Below the 3.7-4.2 GHz Band

7. The receiving devices used in C-band earth stations are designed to listen outside the C-band frequencies allocated for receiving satellite transmissions. These receiving devices are responsible for amplifying the weak satellite signal and converting it into a frequency more suitable for transmission to end-users. Operations below the 3.7 GHz band edge appear in-band to earth station receivers because many receiving devices are designed to pick-up frequencies as low as 3.4 GHz. The systems are designed to listen out of band because there is one global market for this equipment,

[5] For example, the SAS will provide more opportunities if a device can provide accredited out-of-band emissions information, such as compliance with WiMAX or 3GPP standards, but in the absence of this information, could assume the worst case regulatory minimums, such as the -40 dB standard.

and in other parts of the world, C-band operations extend to lower frequencies. Fortunately, this problem of adjacent band interference is readily addressed by the widespread availability of band-pass filters.

8. Many C-band satellite receiver operations already provide a band-pass filter to avoid interference from incumbent government radar systems within range of the receivers. These filters have the capability to limit reception to C-band frequencies by attenuating any signal energy, whether from military radars or small-cell devices, outside the allocated band. Retrofitting the existing receiver apparatus with filters is a straightforward process; the filter simply needs to be mounted inline between the feed horn and the receiving device. C-band band-pass filters are built to pair with commonly used receiving devices, and most C-band feed horns can accept the filter. Once fitted with a band-pass filter, the receiving device will only receive and process signals transmitted on allocated C-band frequencies.

9. The addition of a band-pass filter in the earth station does not have any noticeable impact on receiver performance. These filters have an insertion loss of 0.1 to 0.3 dB, resulting in minimal degradation. Well-engineered installations with filters have no trouble operating today. In fact, Google engineers use filters in all Google Fiber C-band dishes in order to ensure high-quality video reception for our IPTV customers. Equipping our dishes with these filters has provided protection against adjacent band interference without impacting receiver performance. Google C-band dishes are fitted with off-the-shelf filters purchased from the Microwave Filter Company.[6]

[6] Microwave Filter Company, Inc., http://www.mfcsales.com/radarelimination.aspx.

10. Commercially available products provide 30 to 50 dB of protection for out-of-band signals. I recognize that unfiltered C-band receivers at low elevation angles may require significant protection when a small-cell device is operating underneath the beam. However, when I analyzed the impact of a commercial filter, such as the MFC 13961WE WiMax Filter, I concluded that with the use of the filter, the energy received from outside the C-band no longer served as the primary constraint on small-cell device operation. That is, any protection zone required to account for the fact that C-band users are listening out of band is smaller than the protection required to protect C-band users from potential small-cell out-of-band emissions. Put differently, with proper, commercially available filters, C-band users listening out of their band do not operate as a meaningful constraint on CBS operations. This analysis is consistent with the experience of operators in areas where there is already adjacent band usage that would otherwise impact C-band operation—many of these operators have installed these filters precisely for interference protection.

11. Some C-band operators have chosen to install multibeam antennas on their earth stations. Multi-beaming may make filtering more difficult, but there are commercial multi-beam filters available in the market today. Moreover, multibeam operators made a business choice to operate systems that both listen out of the band and may be difficult to retrofit with filters. Those business choices do not constitute a reason to preclude small-cell operations in the adjacent channels. To the extent that multi-beam antennas continue to listen out of their band and cannot be accommodated with filters, C-band operators may consider replacing multi-beam operations with

additional single-beam dishes that together perform the same function as a multi-beam antenna.

Protecting C-band Operations from Harmful Interference Caused By Small-Cell Devices' Out-of-Band Emissions

12. C-band users also raise interference concerns regarding OOBE from small-cell devices. However, the reality is that actual interference—defined as exceeding the recommended ITU interference to noise (I/N) ratio of 0.1—could only occur in very rare combinations of frequency, geographic location, C-band antenna elevation, and device placement relative to the direction of the C-band dish beam.

Effect of physical separation

13. Earth stations are likely to be more susceptible to interference when small-cell devices are in close physical proximity. Propagation loss ensures that the interference from the small-cell device will not reach the earth station when the two are physically separated. The physical distance at which the earth station becomes prone to interference varies with the elevation angle of the antenna receiver, and the placement of the device.

Effect of spectral separation

14. A spectral gap in the frequency bands used by the small-cell device and the earth station can also ensure that the frequencies emitted by the small-cell device will not overlap with the receiving frequencies of the earth station, thereby reducing the likelihood of interference. With awareness of the location of the C-band receivers, a SAS database can readily reject operation in these locations on frequencies that are likely to emit OOBE into the C-band equipment. However, in many cases, significant spectral separation need not be required.

15. Using the parameters submitted by Alion Consulting for a device occupying a 10 MHz channel, analysis reveals that a separation of 14.75 MHz from the C-band is sufficient to reduce the distance needed to attain an interference-to-noise ratio of less than 0.1 by more than 100 times in free space.

16. Using similar assumptions (see Table 1 below) to those used by Alion, a single 10 MHz small-cell device has an in-channel spectral power density of -129.9 dBm/Hz at a distance of 200 meters. Using the 78K system noise temperature from the Alion report, the noise level of the C-band receiver would be -179.7 dBm/Hz. A worst case 10 dB side lobe reduces the effective flux to -139.94 dBm/Hz for the in-channel signal of the small cell. Therefore, any reduction in out-of-band emissions of more than 50 dB is effective in reducing the interference from the small-cell device to an I/N of less than 0.1. Using the WiMax model, a 50 dB reduction occurs *no further than 14.75 MHz from a 10 MHz bandwidth carrier*. Even this assumption is very conservative, as there will be significant additional propagation loss, significant polarization loss (due to the skew of the C-band feed polarizer in relation to the CBS device signal), and absorption by building material, foliage and other terrestrial path blockages.

Parameter	**Value**	
Prop Exponent (r^n)		2
Small Cell Power		23 dBm
Small Cell Antenna Gain		7 dB
Small Cell Bandwidth		10 MHz
C-Band Temperature		78 Kelvin
C-Band Transponder Bandwidth		20 MHz
Small Cell Center Frequency		3.625 GHz
C-Band Receiver Impact	**PSD**	**Channel**
System Noise	-179.68 dBm/Hz	-104.00 dBm
OOBE Flux at Dish	-179.94 dBm/Hz	-104.26 dBm
Received Energy	-189.94 dBm/Hz	-114.26 dBm
I/N	0.09413	

Table 1. Parameters for Spectral Separation Analysis

17. The Alion report apparently considers interference-to-noise ratios by taking into account the entire response bandwidth of the C-band receiver.[7] A more appropriate metric is the interference-to-noise ratio of the individual C-band channels. This treatment separates the low-signal co-channel interference effects from the overload or blocking by strong signals in the adjacent bands. The I/N ratio of a channel adjacent (in this case, below 3.7 GHz) to one on which transmissions are occurring is not relevant for interference determination.

Effect of elevation angle and placement of devices in relation to the C-band beam

18. Increasing the elevation angle of an earth station significantly diminish its susceptibility to interference. The elevation angle is the angle formed between the receiver antenna and the horizon of the earth. When the antenna is aligned along a low elevation angle pointed towards the horizon—as when an earth station in Maine looks at a satellite over Hawaii—it is more likely to pick up interference from terrestrial sources. When the antenna is aligned along a higher elevation angle pointed upwards towards the sky, it is less likely to receive interfering signals from terrestrial sources.

19. The elevation angle required to receive satellite transmissions at any location in the United States can be determined by using readily available satellite look angle calculators.[8] The figure below indicates some representative elevation angles formed by various earth station locations in the United States looking to the westernmost satellite (AMC-8 satellite at 139° W longitude) typically used for television content. This satellite was selected under the assumption that it yields the lowest likely

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[7] *Alion* at 11-12.

[8] As an example, the Satellite Look Angle Calculator, http://www.groundcontrol.com/Satellite_Look_Angle_Calculator.htm.

elevation angle for a given location, and thus the greatest likelihood of interference from CBS devices. Under this most conservative scenario, the earth station look angles vary from approximately 5.2° at the northern tip of Maine, to a more typical 20° to 30° in the center of the United States, to as high as 40° to 50° in the Southwest. As seen in Table 2 and discussed below, elevation angles in the 20° to 30° range or higher allow small-cell operations reasonably close to the earth station.

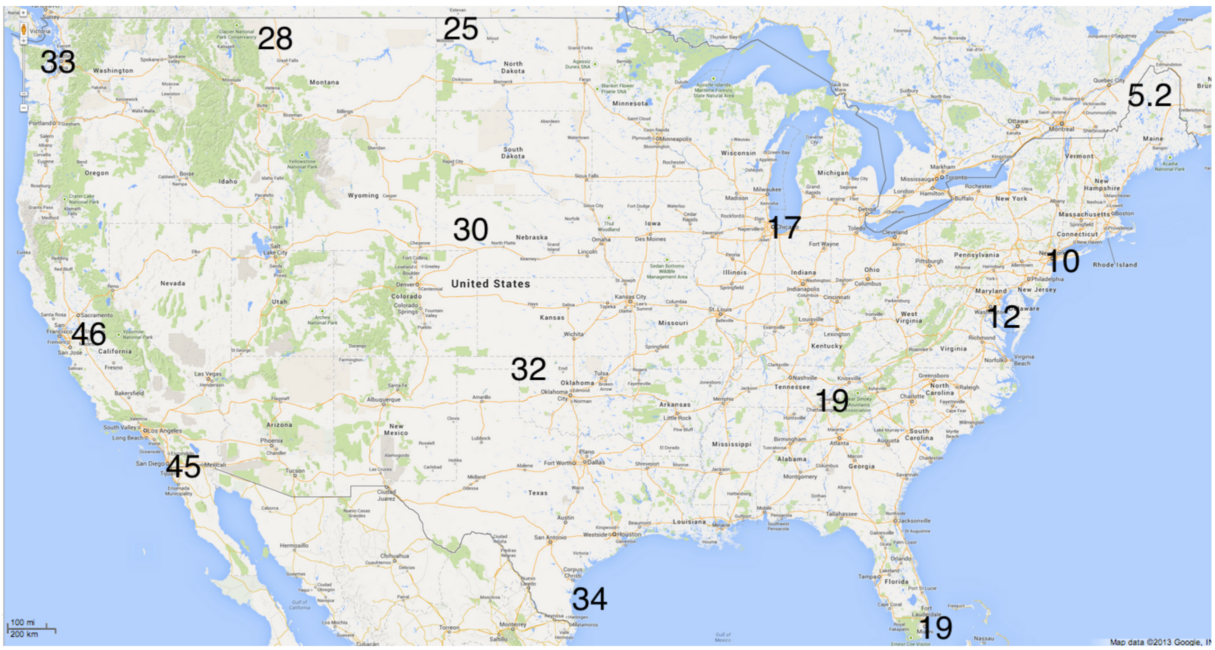

Figure 1. Look Angles from Points in the United States to the Westernmost TV Programming Satellite at 139 Degrees West

20. The location of a CBS device in relation to an earth station's beam is also an important consideration in determining likely signal interference to the C-band receiver. Earth stations point at satellites in the sky, and a small-cell device directly below the line of sight that connects the earth station to the beam is more likely to cause interference. So, for example, because most satellites are located above the earth close to the equator, a small-cell device located north of an earth station located in the United States, rather than south of the earth station, is much less likely to cause

interference to C-band operations. A small-cell device located even 45 degrees off of the main beam of the C-band dish can be anticipated to have approximately -10 dB of gain, compared to 14 dB of gain[9] under the main beam of a 5 degree elevation angle dish. This means that the signal energy received by a C-band receiver from the off-beam device is over 200 times less than the signal energy received from a small-cell device directly under the main beam of the dish. As a result, the relative position of the device and the earth station beam can dramatically reduce the need for protection of C-band operations.

21. Although elevation angle is fixed, an SAS database can dynamically ensure protection by providing the spectral and physical parameters under which small-cell device operation is permitted. The analysis below demonstrates that in most cases, little physical or spectral separation will be required to protect C-band operations.

22. The following conservative assumptions are used in this analysis:

a. The OOBE of the small-cell device is the worst case permitted under the industry WiMAX specifications.

b. The propagation is free space, which is also a worst case assumption. In actual deployment scenarios, the presence of building material and foliage, as well as hills and other terrain changes, will impair propagation.

[9] This analysis uses the same assumptions as the Alion analysis.

c. The dish gain formula, OOBE mask and other parameters are the same ones used in the Alion analysis, as is the ITU I/N ratio of 0.1.[10] All assumed parameters are listed in Table 1, above.

d. The small-cell device is in the center of the 3.55 GHz to 3.7 GHz band contemplated by this NPRM.

23. Separation distances to avoid OOBE interference to the C-band service vary widely. For most of the positions in the vicinity of a C-band receiver, they are less than 250 meters. Directly in the beam of a 5.2° elevation dish, the separation distance as high as 1.67 km, but this protection drops to 250 meters with only ⅛ of a turn from the worst case direction. At this distance, it is unlikely that the terrestrial propagation will be close to free space; accordingly, this analysis probably overstates this distance by double, depending on conditions. In all cases, the actual protection zone area, and thus the user population impacted by any restrictions, is quite small.

24. Furthermore, when there are multiple antennas at one site, the protection zone dimensions will be driven by the lowest elevation angle antenna, and its relationship to the location of the CBS device, which establishes a maximum exclusion distance that simultaneously protects all of the antennas. The protection zones for multiple antennas are not additive at any earth station site, but will significantly overlap.

25. The table below illustrates, for a range of C-band elevation angles, the size of the protection zones required to protect C-band services from a single device in the center of the proposed band (3.625 GHz), using the same WiMAX out of band

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[10] *Alion* at 9.

emissions mask used in the Alion analysis.[11] Different center frequencies, emission masks, or aggregations of deployed devices could alter the dimensions of this exclusion area, making it slightly larger or smaller, but do not change the fundamental dimensions or shape significantly.[12]

C-band Dish Elevation (degrees)	Maximum protection Distance (kilometers)	Excluded Area (square kilometers)
5	1.67	0.55
10	0.92	0.36
20	0.51	0.24
30	0.35	0.20
40	0.27	0.18
48	0.25	0.18

Table 2. Reduction in Protection Area by Increasing Elevation Angle for a Single CBS device

26. The dimensions of the protection zone recommended for an elevation of 20° will suffice across most of the United States. Even making the unlikely assumption that elevation angles are evenly distributed across the values in the table, the average

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[11] *Alion* at 10.

[12] Note that Comsearch calculated protection zones based on scenarios where a number of nodes are in a worst-case position in relation to the CBS device. However, an SAS database will be aware of any aggregation and can avoid this interference in the same way that it protects any other registered device. Therefore, the FCC should not preclude operation completely in these extended zones unless actual density of nodes requires it. In addition, the necessity for a clear path to the satellite inherently reduces the likely density of nodes at low elevation angles. I have assumed that small-cell devices will comply with the Class B standards (or face such operating constraints that their assignability by an SAS database would be limited due to interaction with other CBS devices). I also used the published specifications of the MFC filter cited earlier, which has considerably more rejection in 3.6 to 3.7 GHz.

protection area for a typical earth station would be 0.285 square kilometers. The Comsearch study states that there are 5,000 C-band earth stations in use by the service providers. Using the very conservative assumption about an even distribution of lowest elevation angles, multiplying 5,000 stations by 0.285 square kilometers yields an affected area of only 1,425 square kilometers. *This area represents less than 0.015% of the total United States land mass of 9.8 million square kilometers.*[13]

27. In addition to size, the shape of exclusion zones can be configured to minimize the restricted area. A circular protection zone would unnecessarily limit CBS operation, since the problem of interference is highly directional. The elevation angle of the satellite receiver dictates not only the maximum distance of the exclusion zone from the earth station, but also its spatial characteristics. As depicted in the graphs below, for a low elevation angle, the exclusion zone is likely to be long and located almost entirely in the direction of the receiver elevation angle.[14] For higher elevation angles, the exclusion zone is likely to be smaller but surrounding the satellite receiver more evenly in all directions. It is obvious from the graphs that a fixed radius protection zone would unnecessarily limit CBS operation because, in most directions, the protection distance needed to protect CBS operations is only a fraction of the maximum distance.

[13] Land mass includes bodies of water that are part of the contiguous United States, but not ocean territory or overseas possessions.

[14] Using the assumptions described earlier, these graphs depict the distance a 20-MHz wide channel would have to be separated from the dish location to ensure that the worst-case out of band emissions are below a level of 0.1 I/N for a 78 K system noise temperature receiver. Because C-band satellites are spaced at two degrees in orbit, the dish gain is highly directional, and even a five degree elevation results in much less gain in receiving from the small-cell device. This loss rapidly increases as elevation increases, so that most devices surrounding the dish need only the minimal separation of less than 250 meters. It should be noted once again that these estimates are based on worst-case conditions, and it is likely that they can be refined and significantly reduced as an SAS is implemented.

Thus, even if the maximum protection *distance* is significant, the protected *area* is quite limited. Note that the protection zones will all shrink as devices move farther away from 3.7 GHz, which is the lower bound of the C-band.

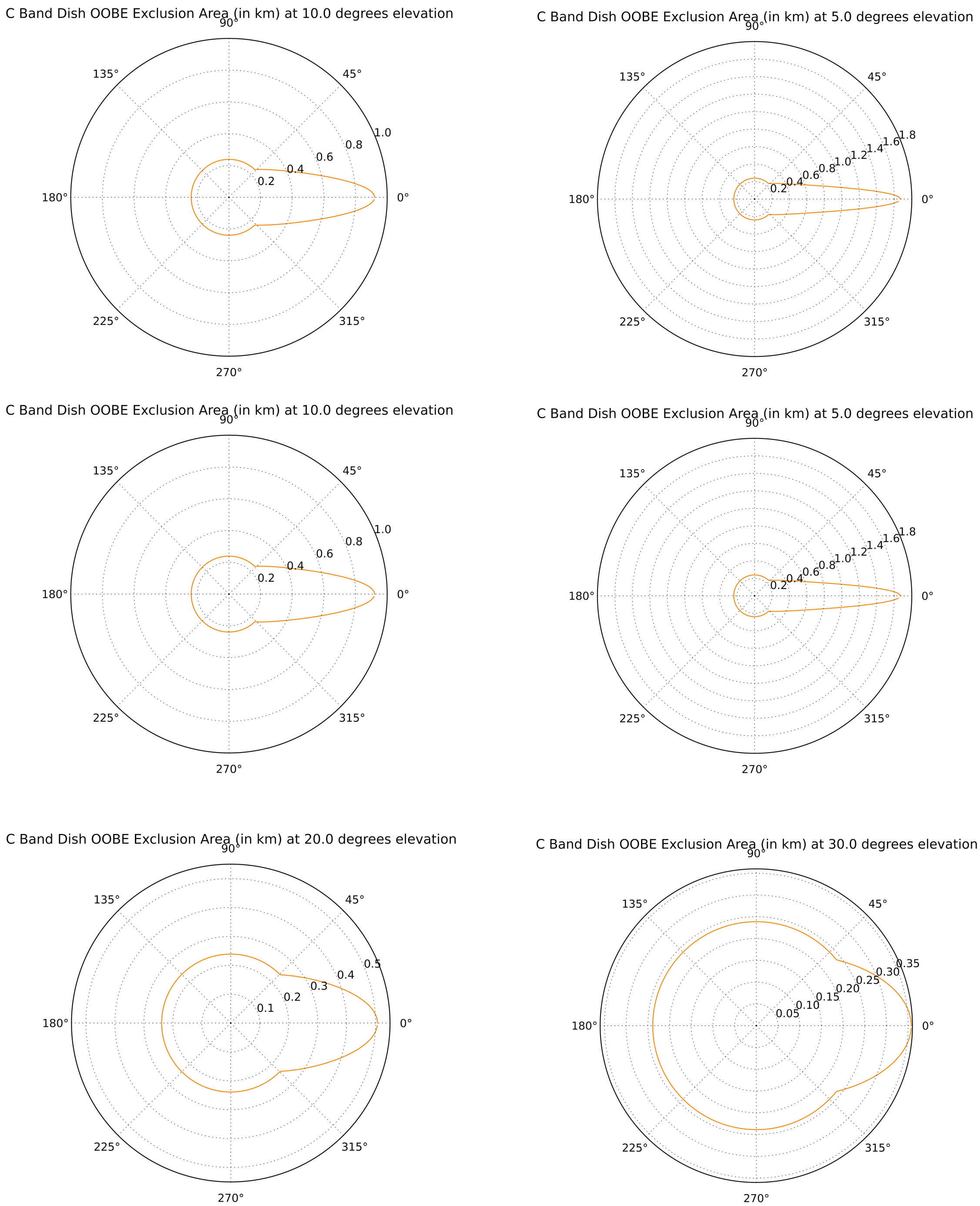

Figure 2. C-band Protection Zones as a Function of Receiver Look Angle

28. To summarize, SAS-provided protection zones will not impact the utility of the small-cell devices for the vast majority of United States citizens. This is especially so because low elevation angle operations require clear terrain—tall buildings, trees, and foliage all preclude effective reception by earth stations. Therefore, earth stations with low elevation angles are typically located away from populated areas, further reducing the impact of these required protections. For example, for a clear line of sight, a C-band dish with a five degree look angle requires a field of view with no building, trees, foliage, or other obstruction higher than 140 meters within a range of 1.67 km from the dish, 43 meters within 500 meters of the dish, or even a two-story house within 120 meters of the reception site.

29. C-band advocates have developed analyses focused on the maximum dimension of the protection zone, based on worst-case assumptions. An advantage of SAS management of interference is that the database can size and shape these protection zones to achieve full protection of C-band operations, while minimizing the impact on small-cell device users.

30. Thus, my conclusions regarding the protection of earth stations in the 3.7-4.2 GHz band are:

a. While OOBE protection zones are necessary, their total extent is well below 0.1% of the US land mass, under any conceivable assumptions, and more likely in the range of the 0.015% number developed above, and therefore the zones should not meaningfully impact the utility of the proposed CBS services.

b. The impact of the exclusion zones will be even less significant than these land mass ratios would suggest, as the constraints of low-elevation C-band placement are inconsistent with the densely populated regions where small-cell use is most likely.

c. The interference drivers cited as grounds for concern (such as C-band dish elevation, CBS device OOBE mask, location and aggregation) can be entered into an SAS database. So long as the locations of C-band dishes are provided, any constraints on operation can readily determined by the database, and suitable protection for documented C-band operations can be provided.

Protecting Earth Station Operations at 3.6-3.65 GHz

31. There are a small number of earth stations (approximately 37) that operate in the band between 3.6 and 3.65 GHz.[15] An SAS database can protect these stations from interference through a combination of spectral separation and protection zones, just as it would protect earth stations in the 3.7 GHz band.

32. A recent study submitted by the Satellite Industry Association grossly overstates potential interference to these C-band operations.[16] The document makes a number of excessively conservative assumptions. First, the document relies on an interference protection standard developed by the International Telecommunication Union to address spurious emissions from other bands; the standard was not meant to address the question of what level of emissions would be appropriate co-channel

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[15] NPRM at ¶ 23.

[16] Letter from Patricia Cooper, President, Satellite Industry Association, to Marlene H. Dortch, Secretary, Federal Communications Commission, GN Dkt. No. 12-354 (filed Aug. 20, 2013) (SIA August 20 Letter), Attach.

operations.[17] Second, the analysis combines terrain assumptions appropriate for a state like Florida with elevation-angle assumptions likely to occur in a far northeastern state like Maine, blending these together into a counterfactual worst-of-worst-case scenarios. Third, the SIA analysis assumes that small-cell devices would have very poor emissions performance, rather than relying on standards like WiMax that approximate the performance of actual devices in the field. Fourth, the SIA analysis assumes that devices could operate at power levels up to 13 decibel-watts, which is many times higher than that proposed for household use.

I, Preston Marshall, declare under penalty of perjury under the laws of the United States of America that the foregoing is true and correct. Executed on September 3, 2013.

Preston Marshall

Preston Marshall

[17] *Compare id.*, Attach. at 6 (citing Recommendation ITU-R S.1432) *with* ITU-R Recommendation S.1342 (2006) at 3 ("There are no Recommendations pertaining to the amount of interference that a digital satellite circuit will receive from systems that share frequencies on a non-primary basis.").